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Canada - Saskatchewan Renewables — Conservation Demonstration Program

Final Report

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CANADA-SASKATCHEWAN CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

On March 18, 1980, the governments of Canada and Saskatchewan entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement, which terminates March 31, 1984, funds the development and demonstration of a wide range of conservation and renewable energy technologies. The program is funded on an equal cost-shared basis by Canada and Saskatchewan, and is administered by Saskatchewan.

The objectives of CREDA are:

— To develop and demonstrate promising new technologies which exploit renewable energy resources, conserve energy, or make its use more efficient;

— To create employment in new or existing industries;

— To develop broad public awareness of the potential of renewable energy and energy conservation technologies.

This report outlines the results of a project funded by the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, and the Government of Canada as represented by Energy, Mines and Resources Canada, under the terms of the Renewables-Conservation Demonstration Program, and contracted with the party identified herein.

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The Swift Current Conservahome

The Retrofit and Rehabilitation of a 1946 Platform-Framed One-and-a-Half Storey House with Full Concrete Basement

Final Technical Report
on a Renewables-Conservation Demonstration Program Project

Conducted By

The Saskatchewan Research Council

And Supported By

Saskatchewan Energy and Mines
and
Energy Mines and Resources Canada

Project Leaders: Dave Eyre and Dave Jennings

Miscellaneous
Report FP-17

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This report gives details of the retrofit and rehabilitation work conducted on a house in Swift Current, Saskatchewan, as part of the Conservahome Project. The project involved the retrofit and rehabilitation of six houses of various ages and styles, and was funded by CREDA: the federal-provincial Conservation and Renewable Energy Demonstration Agreement. For further details of the project the reader is referred to the Overview Report, which is the first in this series of reports on the project.

The city of Swift Current is located in south-west Saskatchewan. It is the largest municipality in the area and was chosen for the Conservahome Project because of its demonstrational potential and its geographic location.

Several houses were being offered for sale at the time of house selection, and six were short-listed on the basis of cost. On inspection, most were found to have basements in poor condition or some structural peculiarities which would have made the retrofit work untypical. The selected house was a 'wartime six' and was similar in design to many thousands of post-war houses across the prairies. It was therefore considered to be an ideal choice for the demonstration of retrofit techniques. The house was well sited for demonstration, with good access and parking facilities.

The Swift Current Conservahome was built in 1946. It was in good condition for its age, and had been subjected to minor modification work. Within the context of the Conservahome Project, this house is of particular interest for the following reasons:

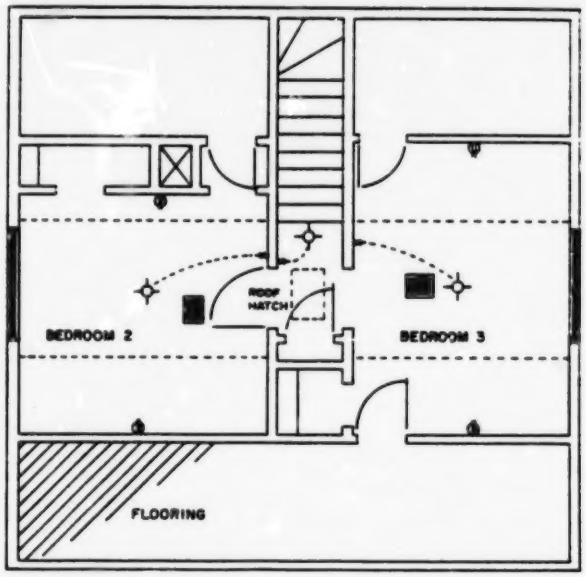
- It was a typical example of the 'wartime six' design.
- The exterior walls were re-insulated by adding rigid insulation to the outside.
- The structural design presents special problems when attempting an airtight seal.
- The heating system was replaced with a state-of-the-art system.

The house is located at Lot 6, Block B, Plan DL 4589. It is on a north-south street with west-facing frontage. It was built in 1946 and plans were not filed with the city building department.

The house is in a low-lying area with sandy soil, and some indications of local flooding. Most of the surrounding houses are of similar age and design, and are generally well-kept. Housing developments such as this, consisting mainly of wartime housing, have a fairly poor market potential even though the houses may be in very good condition. It was therefore recognized at the outset that it would be difficult to justify, or recover, the money spent on retrofit and rehabilitation. The selection of the house was justified mainly by its demonstrational potential and by its applicability to a substantial part of the existing housing stock.

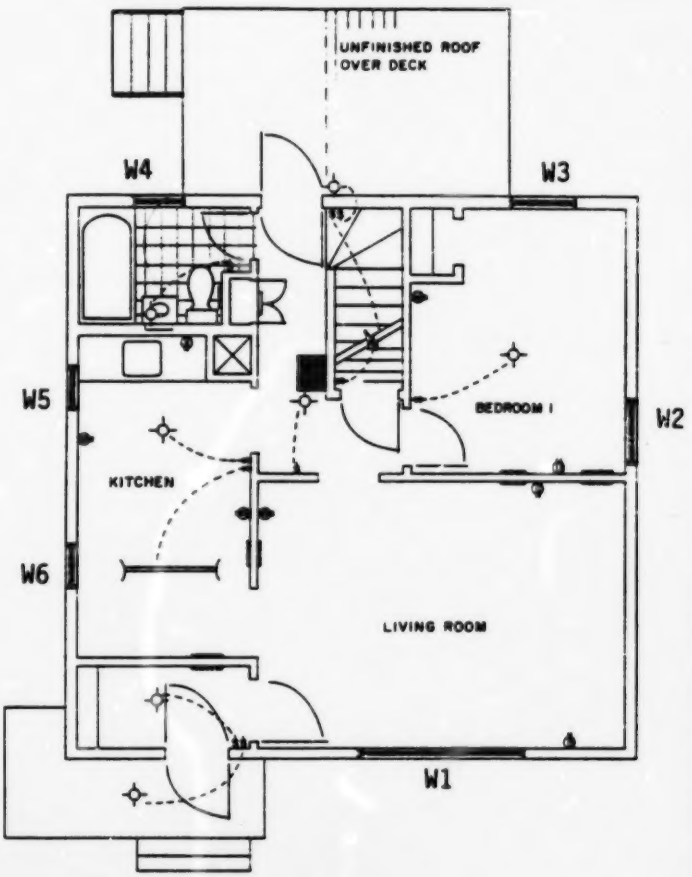
The plans and sectional view of the house are given in figure 1 on the following two pages. These are based on detailed measurements conducted as part of the project. The house is a one-and-a-half storey platform frame structure on a full concrete basement, with a plan area of 56.8 m^2. It is essentially in its original form, the only modifications being a coal storage room in the basement and a raised deck added to the rear of the house.

From discussions with neighbours it was discovered that the houses in the area were prone to basement cracking. Some attributed this to sub-standard concrete work, but they also commented that the area has been flooded occasionally, due to the overflow from a nearby river. The Conservahome basement was generally in good condition, with no obvious signs of flood damage.

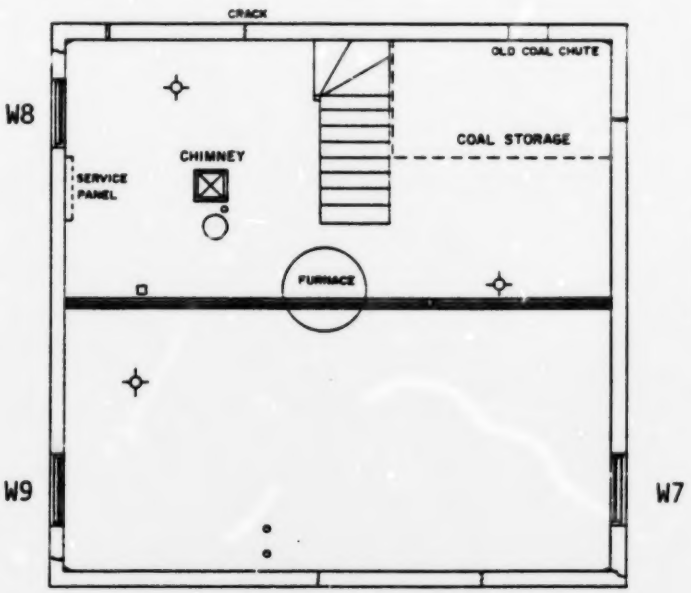


UPPER FLOOR PLAN

Figure 1. Plans and Sectional View



MAIN FLOOR PLAN



BASEMENT FLOOR PLAN

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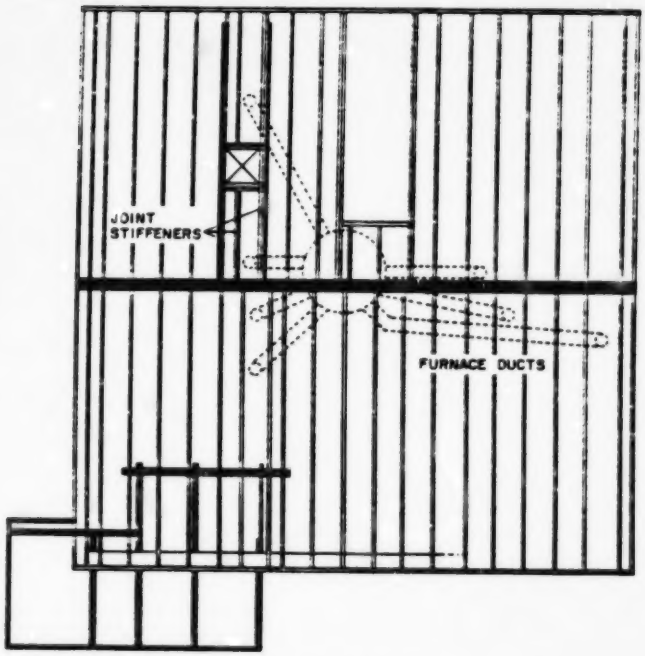
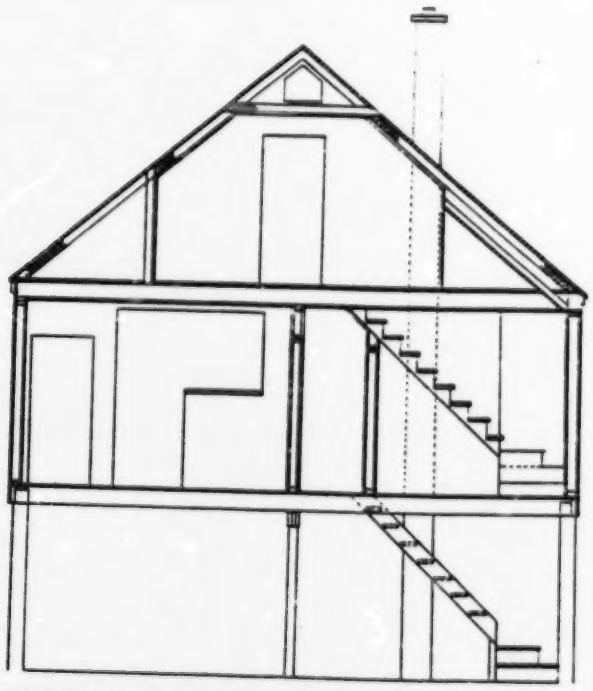


FLOOR JOISTS AND HEATING PLAN

Figure 1. Continued



SECTIONAL VIEW LOOKING NORTH

At the time of purchase the house had been occupied for at least two years by a single, elderly person who had spent some time away from the house. The occupancy pattern was therefore low and irregular, making it difficult to draw conclusions about internal heat gains.

The house was heated by a solid fuel-fired furnace that had been converted to natural gas usage. It was a large unit, with large heating ducts, and occupied a large part of the basement area. Furnaces of this type are not uncommon in houses of this age, and are known as 'octopus' furnaces. The domestic hot water heater was a 'standard' natural gas unit.

With the permission of the homeowner, the natural gas and electricity bills were obtained from Saskatchewan Power Corporation for the period July 1979 to July 1980.* The gas usage of the domestic hot water system was estimated from the summer gas bills, and was assumed to remain constant throughout the year. This gave the following breakdown for the annual gas consumption:

Space heating (natural gas)	3907 m^3
DHW heating (natural gas)	1415 m^3
Total	5322 m^3

The heating degree-days for Swift Current is 5498 (degree Celsius days) based on 30-year average data. The actual heating degree-days over the period covered by the fuel bills was 6153 °C.d. Hence, by pro-rating according to the heating degree-day figures, the space heating consumption of the house in an 'average' year would be:

Space heating (average year)	3491 m^3

* As it turned out, some difficulties were experienced in getting the electricity bills.

There are inconsistencies in this breakdown of gas consumption. The average annual gas consumption for domestic hot water heating, in Saskatchewan, is about 1302 m^3 (46 Mcf). For a single person, living intermittently in a house, the DHW gas consumption should be considerably less than average. A figure of 550 to 600 m^3 would be more appropriate. It would therefore appear that the summer gas usage, as recorded on the fuel bills, was in some way atypical or did not totally represent DHW usage.

A more realistic breakdown of the gas consumption, assuming 600 m^3 for DHW heating, would be as follows:

Space heating	4722 m^3
DHW heating	600 m^3
Total gas usage	5322 m^3

Although it would be hard to justify such a breakdown, it is felt that it gives a more accurate indication of each of the gas usage components for a house with a low level of occupancy. Taking the space heating consumption, and correcting it for heating degree-days, we obtain:

Space heating (average year)	4219 m^3

The space heating demands of the house have been calculated theoretically, using the measured dimensions and estimated thermal resistances in the house envelope. The result was:

Calculated space heat demand	109.5 GJ

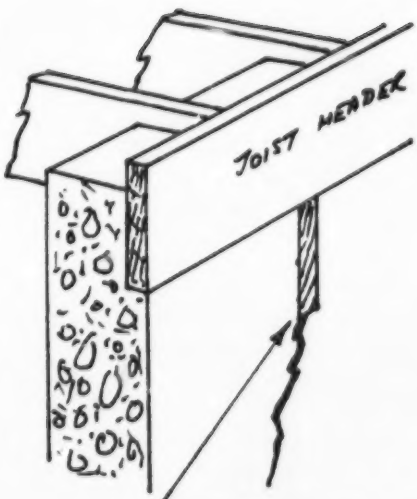
Using the measured furnace efficiency of 66%, this corresponds to an annual space heating gas consumption of 4457 m^3. This figure shows good agreement with the revised space heating estimate of 4219 m^3.

4.1 Assessment

The basement was in very good condition for its age, with very little evidence of alkaline attack. The floor was smooth, with a few minor cracks. The walls contained three major cracks, extending vertically over the full height of the wall, and four minor ones. All were clean cracks and would present no trouble when grouting.

An 'octopus' furnace - a solid fuel-fired appliance converted to natural gas - occupied a central position in the basement and had obviously prevented any development of the basement as useful living space. One corner of the basement contained a light structure that was used originally for coal storage. The original coal chute was still in place, but had been covered over with a wood panel.

The floor joists and main storey shiplap subfloor were generally in good condition, though there had been some careless saw work on the joists around the chimney. These joists had been weakened by deep saw cuts (the reason was not clear) and required strengthening.



EXPOSED JOIST END MAY CAUSED CRACK IN FOUNDATION WALL

In its original form, the house had a set of steps and a small deck at the back door. This structure was supported on joists extending through the concrete foundation wall into the basement. The structure had been removed and replaced by a larger deck showing rather poor workmanship. As part of this modification, the original supporting joists had been sawn off, flush with the outside of the foundation wall. Over the years, the exposed ends of the joists probably absorbed water and expanded, causing local cracking of the foundation wall. One of the major cracks in the foundation wall appeared to have been started in this way.

The basement stairs were badly deteriorated, and would need to be replaced to handle the traffic during the demonstration phase.

The basement constituted a major source of heat loss from the house - it was estimated to account for at least 35% of the total heat loss, taking air infiltration into account. The basement was uninsulated and had about 600 mm of exposed foundation wall above grade. This accounted for a large part of the transmission heat loss. In addition, there were several infiltration openings around the foundation walls. These openings included:

- Cracks in the foundation walls.
- Gaps around the coal chute panel.
- Gaps at the junction of the wood frame and the foundation wall (the floor joists were set into the concrete, according to common prairie practice).
- Gaps around the deck support joists where they passed through the foundation wall.

4.2 Retrofit Alternatives

Before deciding on a retrofit strategy for a basement, it is essential first to consider the condition of the basement and the possibility of raising the condition to an acceptable level. It would be unwise to conduct major retrofit work on a defective basement without first making some effort to repair the defects.

In cracked basements, such as this one, the first question to ask is: what caused the cracks in the first place? The answer is of paramount importance in determining the appropriate rehabilitation and retrofit strategies. For example: if the cracks were caused by soil activity or water table effects, then there would be no sense in repairing the cracks unless something was also done to correct the cause of the problem. In short, if rehabilitation work is to be done on a basement, it should be directed at the cause of the problem rather than at the symptoms. Unfortunately, it is not always easy to determine the cause of basement cracking. It requires experienced inspection skills that have never been systematized or put down on paper.

This particular basement provided several clues to the cause of cracking:

- The cracks were clean and vertical, and usually located near a corner. This suggested that they were tension cracks caused by poor concrete installation.

- There were no inward bulges or associated cracks in the centre sections of the walls - such as might be produced by excessive soil loading. This was consistent with known sandy soil conditions around the house.

- The basement floor displayed only minor cracks, with no detectable signs of floor heave. This suggested that the drainage was good and tended to confirm that the soil was inactive.

It was therefore concluded that the cracks were caused primarily by either poor concrete quality or by poor concrete installation technique. Taking this as a correct reading of the clues, it followed that a good quality grouting job would put the basement in good condition for many years.

This led to a further consideration: whether to grout from the inside or the outside? The cracks extended cleanly from the inside to the outside of the foundation wall. If they were to be grouted on the inside only, this would certainly seal the cracks against air leakage and water infiltration. However, it would also leave large sections of the cracks exposed on the outside. Given the sandy soil conditions and the possibility of flooding in the area, it was felt that sand would easily infiltrate into the cracks, providing a matrix for water build-up. With the worst conceivable combination of climatic effects, this could lead to freezing of water in the cracks, which, through expansion, would tend to open up the cracks once again. Therefore, for this particular basement, it would be advisable to grout the cracks from the outside.

Given a proper rehabilitation of the basement, the retrofit alternatives reduce to the following:

- Do nothing but remedial sealing of cracks. This would reduce air infiltration heat losses slightly, but would not have any great effect on the overall performance of the house.

- Seal all infiltration openings. This would further reduce the infiltration heat losses, but its effect on the overall thermal performance of the house would be typically 10% or less.

- Seal all openings, and apply insulation on the inside. This would give much greater energy savings, but was considered to be inadvisable because of the condition of the basement. When a foundation wall is insulated on the inside, the foundation and the soil around the house are deprived of the heating effects of the house. As a result, they experience larger annual temperature swings than before retrofit. It was felt that this basement, with its suspected weak concrete, might not withstand the more severe temperature effects. There might therefore be some risk of opening up the cracks by thermal expansion and contraction cycling.

- Seal all openings and insulate from the outside. This was considered to be the best option: it would give substantial energy savings and would provide further protection of the foundation wall by insulating it from climatic temperature swings.

4.3 Factors affecting the choice

In the discussion so far, it has been shown that, for technical reasons, it was advisable to grout and insulate the foundation wall from the outside. But would this strategy make sense from the point of view of cost effectiveness? To answer this question, several other factors have to be taken into consideration.

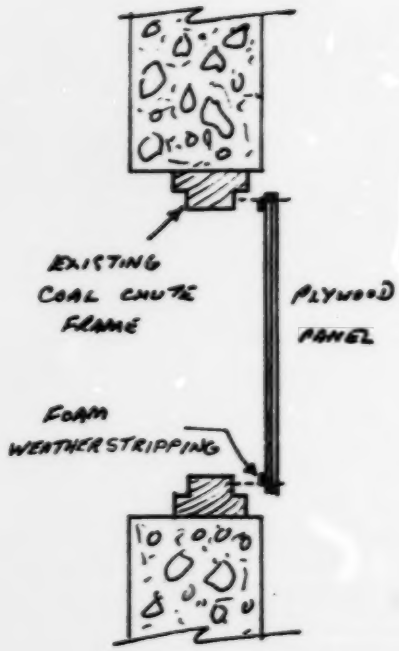
- For reasons that will be discussed later, it was considered appropriate to insulate the main house walls from the outside. This work could be extended downwards to include the foundation wall. As part

of the work on the main walls, it was planned to install a new air-vapour barrier over the outside of the house envelope. This also could be carried down the foundation wall, and would constitute a very efficient and cost-effective way of sealing the infiltration points at the junction of the wood frame and the concrete foundation.

- The need to grout the cracks from the exterior meant that some excavation would be required around the foundation. This could be extended to give full access to the foundation walls for insulating and sealing work.

- There were relatively few obstructions around the house to get in the way of foundation work. There were no large concrete pads at the doors, and no extensive paving around the house. The decks at both the front and rear doors were considered to be sub-standard, and it was proposed to remove them anyway. Consequently, the cost of excavation and foundation work was not expected to be high.

It was therefore decided to grout the foundation wall cracks from the outside, with additional grouting on the inside as a precaution. The foundation wall was to be sealed and insulated from the outside, as part of the main wall retrofit.



4.4 Details of the upgrading work *

The existing cover on the coal chute was removed, leaving only the wood frame. Caulk was applied around the edges of the frame, to seal the gap between the frame and the concrete. A new plywood panel was installed. This was provided with foam sealing strips and was attached by screws. During the demonstration phase this panel could be removed to show the exterior insulation and vapour barrier.

The existing basement stairs were removed and replaced by new ones.

The joist stubs from the rear deck were removed, and the holes were filled with mortar.

* The detailed specifications of all upgrading work are given in Appendix I, which consists of specifications taken from the contract documents.

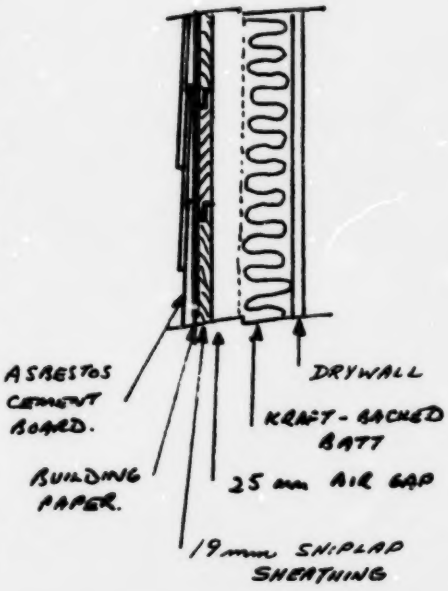
The existing coal storage enclosure was removed and the basement was given a general clean-up.

Floor joists consisting of 38mm x 235 mm fir, were nailed to each side of the defective joists to provide reinforcement in the region of the chimney.

As part of the exterior excavation work, to be described later, the excavations were taken down to the footings around all visible cracks. The cracks were widened with a chisel, then thoroughly cleaned. Grouting material, selected for its strength and elasticity, was applied to the prepared cracks. The same procedure was repeated on the cracks from inside the basement.

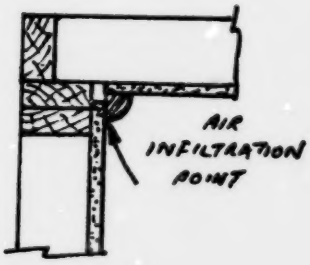
The exterior sealing and insulation of the foundation wall will be included in the wall upgrading details in the following section.

5.1 Assessment



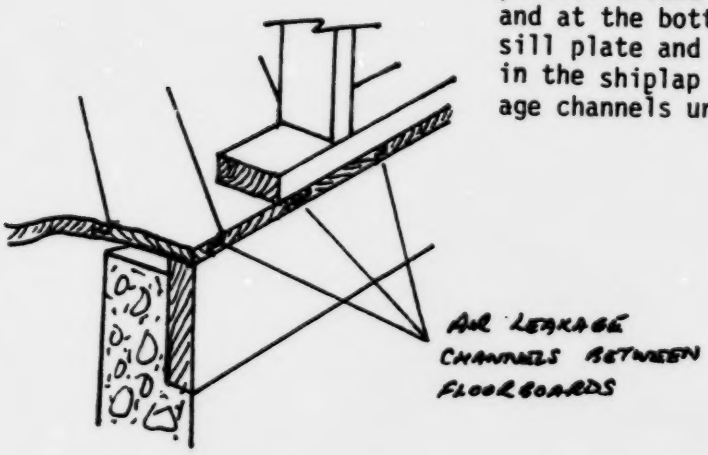
The exterior walls were of normal platform frame construction, with 38 mm x 89 mm studs on 400 mm centres. The insulation consisted of Kraft-backed mineral wool batt, with an installed thermal resistance of RSI 1.23. However, due to deterioration its actual thermal resistance may have been as low as RSI 0.88. This type of batt insulation has an integral paper-type vapour barrier which is stapled to the front face of the wall studs. The batt is about 64 mm thick, and with the normal method of installation this leaves an air gap about 25 mm wide on the cold side of the batt.

The exterior was finished with 19 mm shiplap sheathing, building paper and siding. The siding was of a type that was popular in the 1940's, consisting of panels of ripple-finish asbestos-cement board. This had deteriorated at several points; cracks and broken sections were visible around the bottom edge of the siding and at the house corners.



The interior was finished with 9.5 mm drywall and paint. On the wall and ceiling sections the drywall joints had been properly taped and sanded, but no taping had been done on corner joints. The corner joints were covered with quarter-round wood moulding, which had lifted away from the drywall at many points. This had created a large area for air leakage.

Other infiltration points were found in the usual places: around windows and doors, electrical outlets, and at the bottom of the exterior walls, between the sill plate and the shiplap sub-floor. The gaps in the shiplap construction were acting as air leakage channels under the sill plate.



5.2 Retrofit Alternatives

The exterior walls were losing heat in two ways: by thermal transmission through a thin layer of insulation, and by infiltration through the large number of air leakage points in the structure. The required retrofit work would have to deal with each of these aspects.

There were three basic options for retrofitting the exterior walls:

- Add more insulation inside the wall cavity, using the existing 25 mm air space.
- Add insulation and air-vapour barrier to the inside face of the walls.
- Add insulation and air-vapour barrier to the exterior face of the walls.

The first option can be dismissed easily; the 25 mm air gap is too narrow to guarantee a good fill with poured or blown insulation. Furthermore, such work would give only a marginal improvement to the thermal performance of the walls. This option would also involve some intricate sealing work at wall corners and in the gaps between floorboards. Foam insulation was considered, but was rejected because of possible undesirable interactions with the existing insulation.

The interior approach requires the installation of insulation on the interior face of the wall. This can be done either with rigid insulation or with an added wood frame containing batt insulation.This technique also creates the opportunity to install an airtight vapour barrier over the treated wall sections. In this instance, the technique had several disadvantages:

- It would involve major construction on walls which were already in good condition.
- It would reduce the size of the rooms, which were already fairly small.
- Some parts of the exterior wall could not be accessed without major reconstruction. These included

areas covered by the kitchen furnishings, the bath-tub, cupboards, etc.

- The technique would not constitute a complete solution of the air leakage problem. Extra sealing work would be required at the subfloor cracks. Even if this were done, a number of inaccessible air leakage points would still exist at the junctions of the partition and exterior walls.

The exterior approach involves the installation of an air-vapour barrier and insulation around the exterior of the house. The insulation may consist of rigid type, attached directly to the walls, or batt type installed in an added wood frame. The technique is potentially capable of giving high levels of airtightness, but it suffers from several disadvantages:

- It is costly to install new cladding over the exterior insulation. This, however, is not an issue when the house needs new cladding anyway - and this technique has some advantages in such cases.

- It is not always possible to treat the whole wall. Features such as steps, concrete pads, exterior structures, etc., are sometimes better left in place.

- The technique involves a lot of related work, such as excavation, backfill, removal and relocation of exterior fixtures, extension of window frames and door frames, etc.

- Being exterior work, it must take account of weather conditions. The air-vapour barrier envelope will need secure fastening if there is any risk of high winds.

5.3 Factors affecting the choice

For the exterior walls alone, there was little to choose between the interior and exterior techniques. But when the basement was taken into account, the exterior technique emerged as the best choice. The basement required exterior work, and this created an opportunity to apply exterior insulation on both the wood frame and the foundation wall - as a single retrofit job.

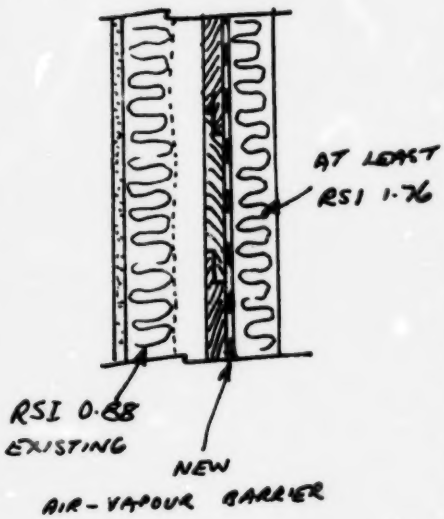
This choice was supported by the condition of the exterior siding. The siding could have lasted for a few more years, but its appearance detracted from the value of the house and it was considered advisable to replace it.

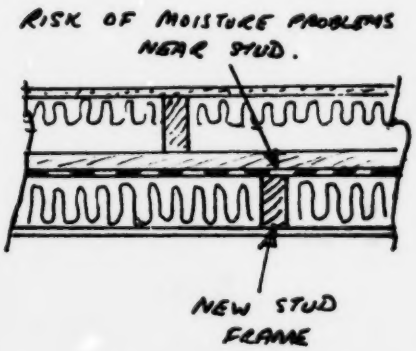
On this house there were relatively few obstacles in the way of the exterior technique. The main obstacles were the front and rear decks, both of which were in poor condition and needed replacing. There were no trees or shrubs close to the house, and no concrete pads or paving keyed into the foundation wall. A small concrete path ran around one side of the house, about 300 mm clear of the foundation. Its removal and replacement would not involve large cost penalties. With the removal of these various obstacles, there would be full access to the exterior wall. The only remaining considerations were the various fixtures on the outside of the house, including doors, windows, utility inlets, exterior lights etc.

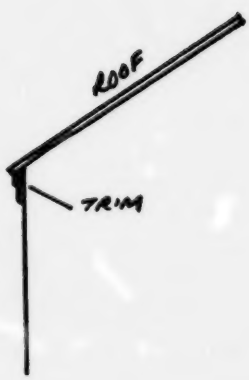
It was therefore decided to try an exterior retrofit technique on this house. Fan depressurization tests revealed that this house was the leakiest of the six Conservahomes. A high priority was therefore assigned to the sealing of the house, and it was proposed to overcome most of the problem by wrapping a tightly sealed air-vapour barrier around the outside of the house - terminating 600 mm below grade. This would block most of the air leakage channels in the basement and the exterior walls.

There were two alternative ways of adding insulation to the exterior: nailing rigid insulation to the existing wall sheathing, or building a new wood framed wall on the outside of the house and filling it with batt insulation. The choice involved several considerations:

- When retrofitting an exterior wall, care has to be taken in positioning the air-vapour barrier. A dewpoint problem can arise if the air-vapour barrier is located too close to the exterior face of the wall. This may lead to moisture accumulation and structural damage within the wall. To avoid this, it has become the accepted practice to have twice as much insulation on the cold side of the air-vapour barrier as on the warm side. For all







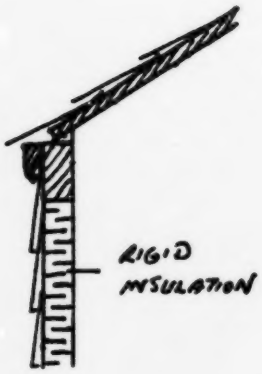
practical purposes the existing wall vapour barrier could be discounted, since it was effectively by-passed by all the air leakage channels in the structure. The new air-vapour barrier wrapped around the outside of the house, would constitute the proper vapour barrier of the wall. The insulation level on the warm side of this air-vapour barrier was known to be in the range RSI 0.88 to RSI 1.23. Therefore, it would be necessary to install at least twice this level on the outside of the air-vapour barrier, namely RSI 1.76 or greater.

This level of insulation could be achieved easily by adding a 38 mm x 89 mm wood frame wall on the outside of the existing wall. If this was supported tightly against the wall, it would accept glass fibre batt with an insulation level of RSI 2.11, which would be adequate. However, it is important to note that the studs themselves have poor insulation properties, and a dewpoint problem might occur within the wall at the air-vapour barrier, close to each stud. This point is a theoretical one that has never been investigated in practice. The potential for moisture damage exists, but there may be other mechanisms at work to prevent such damage.

- Rigid insulation, such as 50 mm extruded polystyrene, will give an outside insulation level of RSI 1.76. This is only marginally acceptable under the requirements of the two-to-one rule. The two-to-one rule relates to a typical prairie climate and contains a small safety margin. The Swift Current climate is somewhat more moderate than at most locations in the prairies, and therefore a 50 mm layer of this type of rigid insulation was felt to be quite adequate. Thicker layers of rigid insulation would, of course, avoid the dewpoint problem completely. But as the thickness of rigid insulation is increased, it becomes more difficult to ensure firm attachment of the siding. The 50 mm thickness is the best compromise in this situation.

- In choosing between the wood frame and the rigid insulation technique, the determining factor was the design of the roof. The roof had no overhangs, either on the sloping sections or the gables. There was a slight roof overlap at the top of each wall, and this was finished off with a trim board. Therefore, when insulation is added to the outside of

this house, it follows that the roofline must be extended to cover the new work. Some care must be taken to secure the wall addition at the roof line, and to cover it so that water cannot enter the new wall structure. With the wood frame technique it would have been necessary to extend the roofline at least 150 mm. Good construction practice required that this be done by cutting back the existing roof sheathing by at least 400 mm, then installing new sheathing to extend over the top of the new wood frame. Under normal circumstances, the wood frame technique is marginally more cost effective than the rigid insulation technique, but with this extra roof construction and its associated extra costs, the wood frame technique becomes the less cost effective of the two.



It was therefore decided to adopt the rigid insulation technique, using a 50 mm layer of extruded polystyrene rigid insulation with a thermal resistance of RSI 1.76. This technique would add only 50 mm to the wall thickness, and this could be accommodated with a simple 50 mm x 89 mm trim board at the roof line.

5.4 Details of the upgrading work

Preparation:

The front and rear deck structures, including canopies, were dismantled and removed. This gave access to the sawn-off deck joists under the rear door, which were then removed and the holes mortared, as described in the basement section.

The electrical service was temporarily disconnected at the service pole. The service inlet mast, meter, anchors and all other electrical fixtures on the house exterior were removed. The cables for exterior light fixtures were left in place for re-connection later.

The telephone cable and fixtures were disconnected and temporarily removed.

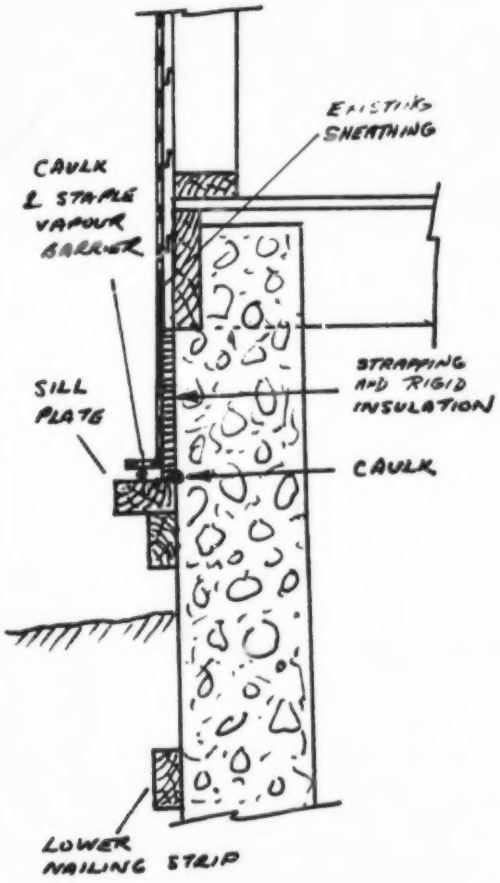
The attic gable vents were removed. The vent on the south wall was blocked-in permanently with a plywood panel. The vent on the north wall was converted to an attic hatch, for reasons that will be given later.

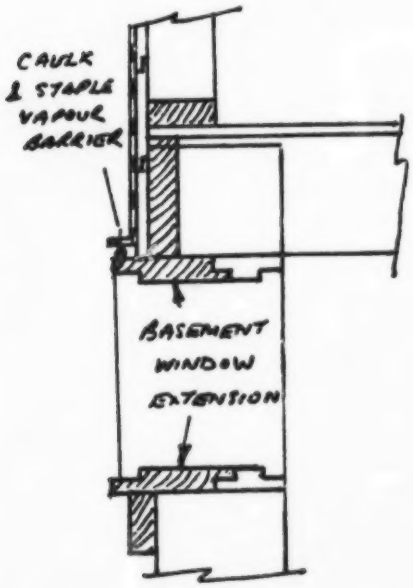
All exterior fixtures, including doorbells and mail-box, were removed and stored.

The storm doors and fittings were removed and stored. Storm windows were removed, given identification marks and stored. Brick moulds around doors and windows were removed and discarded. This gave access to the window and door frames in preparation for the construction of frame extensions.

The siding was removed and discarded. The revealed surface was inspected carefully for nails and sharp edges that might puncture the newly-installed air-vapour barrier. [Note that in some houses, at this stage, the inspection might reveal moisture damage on the sheathing. If this is found, it may mean that the outside surface of the wall (sheathing, sheathing paper and siding) is less permeable to moisture movement than the inside layer (drywall and leaky vapour barrier). When the new, well-sealed air vapour barrier is installed on the exterior, this will effectively stop all outward movement of moisture, and it might be thought that this will lead to condensation and moisture damage on the warm side of the vapour barrier. However, by adding twice as much insulation outside the air-vapour barrier, this problem of moisture accumulation can be avoided]. No moisture problems were detected in this case, and all nails and sharp edges were removed or hammered flat.

All paving was removed from around the house, and the soil was excavated around the foundation wall to a depth of 1 metre. The excavation was extended down to the footings around all cracks, to allow repair of the cracks, as mentioned earlier. Also at this stage, the gas service inlet was modified by moving it about 100 mm away from the foundation wall, so that it would clear the extended wall surface.





Just before the air-vapour barrier was installed, the two doors and some defective windows were removed and replaced by new units. The need for this will be described fully in a later section.

Air-vapour barrier installation:

A nailing strip and sill plate, each 38 mm x 89 mm pressure-treated spruce, were attached continuously around the house, 150 mm above grade. This would act as a support for the bottom edge of the air-vapour barrier, and it was therefore important to obtain a good seal between the sill plate and the foundation wall. Caulking was applied generously along the joint of the sill plate and the concrete foundation.

A lower nailing strip. of 38 mm x 89 mm pressure-treated spruce, was installed around the house about 600 mm below grade. This would serve as a support for the below-grade insulation at a later stage.

To provide a nailing base for the bottom rows of siding, 25 mm x 89 mm vertical strapping material was attached 600 mm on center between the new sill plate and the bottom edge of the existing sheathing. Panels of 25 mm thick rigid insulation was then installed between the vertical strapping to provide a flat, continuous surface between the sheathing and sill plate.

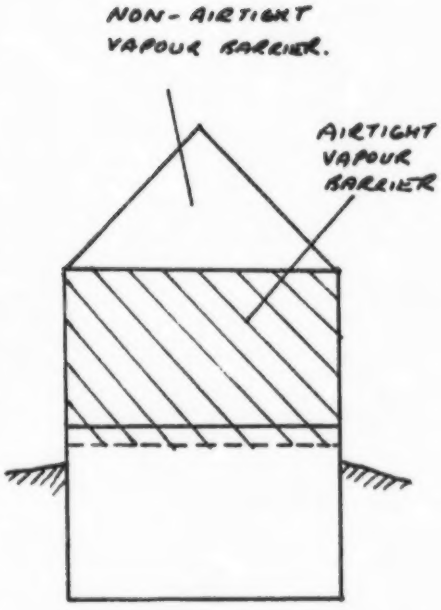
The basement windows were removed and the frames were extended to match the new wall installation.

The air-vapour barrier installers were asked to try to conduct the work during a period of low wind, but precautions were taken against wind damage. The air-vapour barrier, consisting of 0.150 mm polyethylene sheet material, was installed in sections as large as could be handled. Adjoining sections were overlapped, caulked and stapled along the joints. The air vapour barrier was secured to the sheathing by staples, driven through sections of glass fibre tape to prevent pull-off under wind loading. The aim was to construct a perfectly sealed envelope around the house walls.

At the bottom, the air-vapour barrier was caulked and stapled to the new sill plate, and was also caulked and stapled around the basement window frame extensions, as shown in the sketches on the preceding page. At the top, the air-vapour barrier was terminated at the top plates of the exterior walls, and was caulked and stapled all round the house to give a sealed joint. This detail will be discussed later in the section dealing with the attic air-vapour barrier.

Around cables, service inlets and other obstacles, the polyethylene was caulked and sealed to make an airtight joint. The polyethylene sheet was trimmed at windows and doors, allowing plenty of spare material for sealing around the frames. It was then caulked and stapled to the front face of each frame, and then was trimmed so that it would not be visible once the frame extensions were in place.

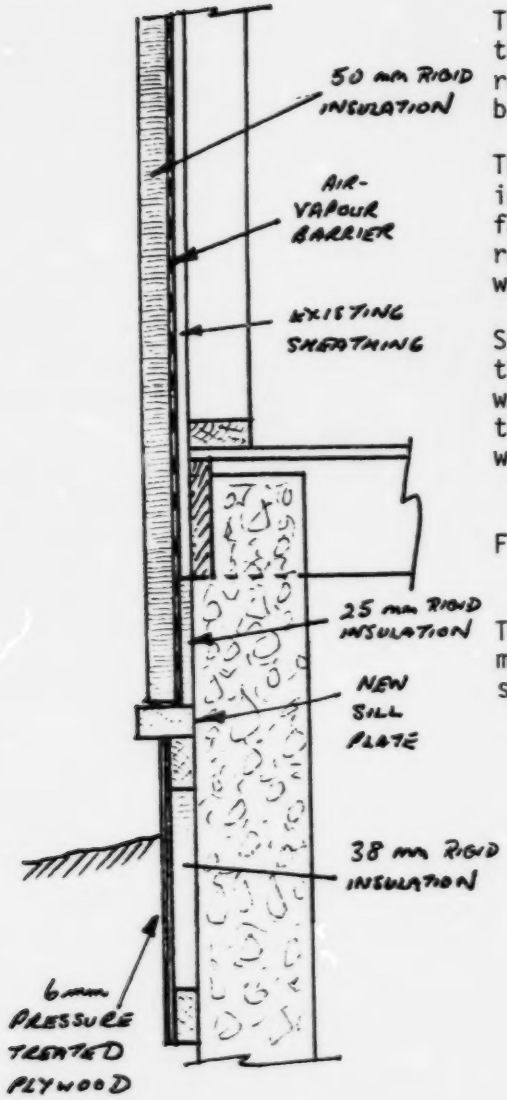
Finally, before proceeding with the insulation work, the air-vapour barrier was inspected for holes and rips, which were repaired with pieces of polyethylene, caulk and staples.



These procedures gave an airtight vapour barrier around the house walls, extending from the top plates of the walls to a level about 150 mm above grade. It therefore sealed all the air leakage points in the walls, and it also sealed the many air leakage channels around the edges of the floor structure.

Further sections of polyethylene sheet were added to the gable walls above the top plates of the main wall structure. The intention here was to provide an air-vapour barrier that could be continued inside the attic. It was anticipated that there would be little chance of achieving an airtight construction around the attic, therefore no effort was made to give an airtight construction on these sections of polyethylene.

Insulation:



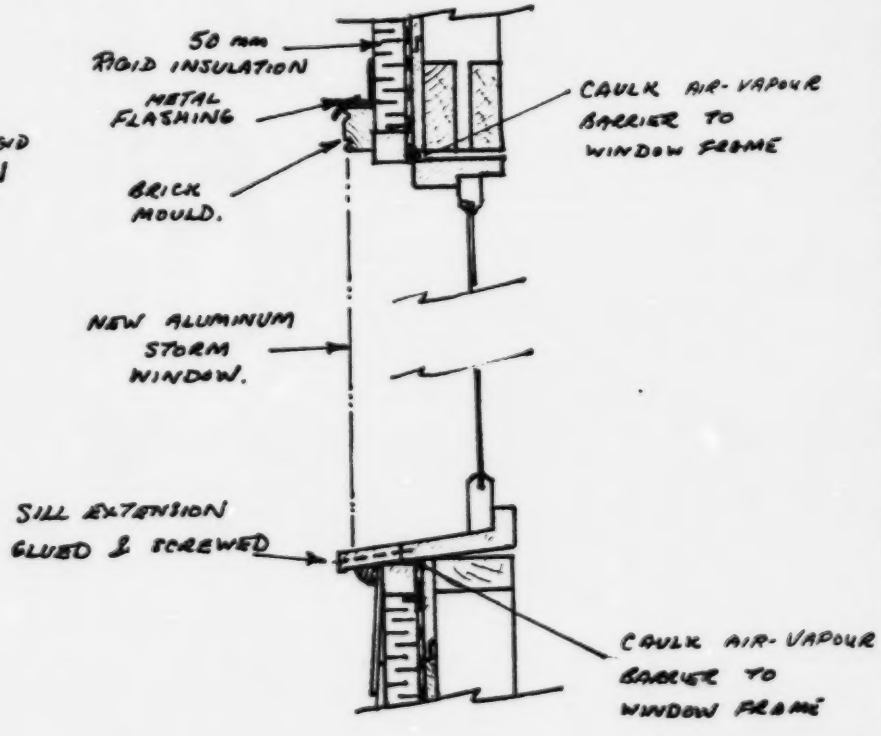
The insulation work was installed promptly after the completion of the air vapour barrier work, to reduce the risk of wind damage on the air-vapour barrier.

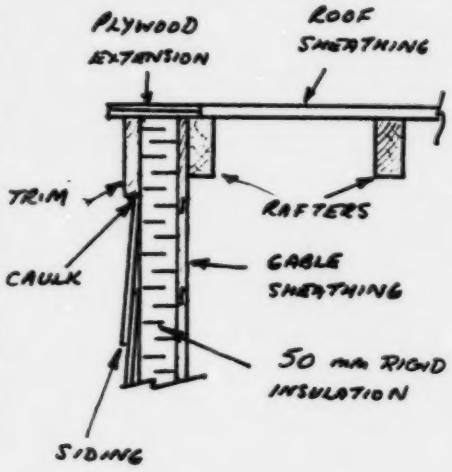
The exterior walls were covered with 50 mm rigid insulation, attached to the sheathing with appropriate fasteners. The entire wall area was covered, from the roof-line down to the new sill plate on the foundation wall.

Sheets of 38 mm rigid insulation were installed between the upper and lower nailing strips on the foundation wall. This area was then covered with 6 mm pressure-treated plywood, which was painted before the soil was backfilled.

Finishing around windows:

The window frames were extended and were fitted with metal flashing and brick moulding as shown in the sketch below:


50 mm RIGID INSULATION
METAL FLASHING
BRICK MOULD.
CAULK AIR-VAPOUR BARRIER TO WINDOW FRAME
NEW ALUMINUM STORM WINDOW.
SILL EXTENSION GLUED & SCREWED
CAULK AIR-VAPOUR BARRIER TO WINDOW FRAME



Finishing at the gable ends:

The shingles, which were to be replaced anyway, were removed from around the edges of the roof. The roof sheathing was cut back a few millimetres, to expose enough framing for attaching a plywood extension. The rigid insulation was carried up to this extension and a 20 mm x 140 mm trim board was fitted.

Siding:

The exterior was finished in X-90 colorlox lap siding, considered to be adequate for the remaining lifetime of the house.

Miscellaneous finishing work:

The soil was backfilled around the foundation wall and sloped away from the wall to improve drainage. New eavestroughs and downspouts were fitted, and splash-pads were provided.

A new electrical mast, entrance wiring, service panel and breakers were installed. All services (electricity, gas and phone) were reconnected. Frost-free hose bibbs were installed on the existing water lines.

All exterior fixtures (porch lights, doorbells, mailbox, etc) were re-installed.

New paving slabs were installed from the front to the rear of the house. New steps, with small decks, were installed at the front and rear doors.

Finally, all new woodwork was painted.

6.1 Assessment

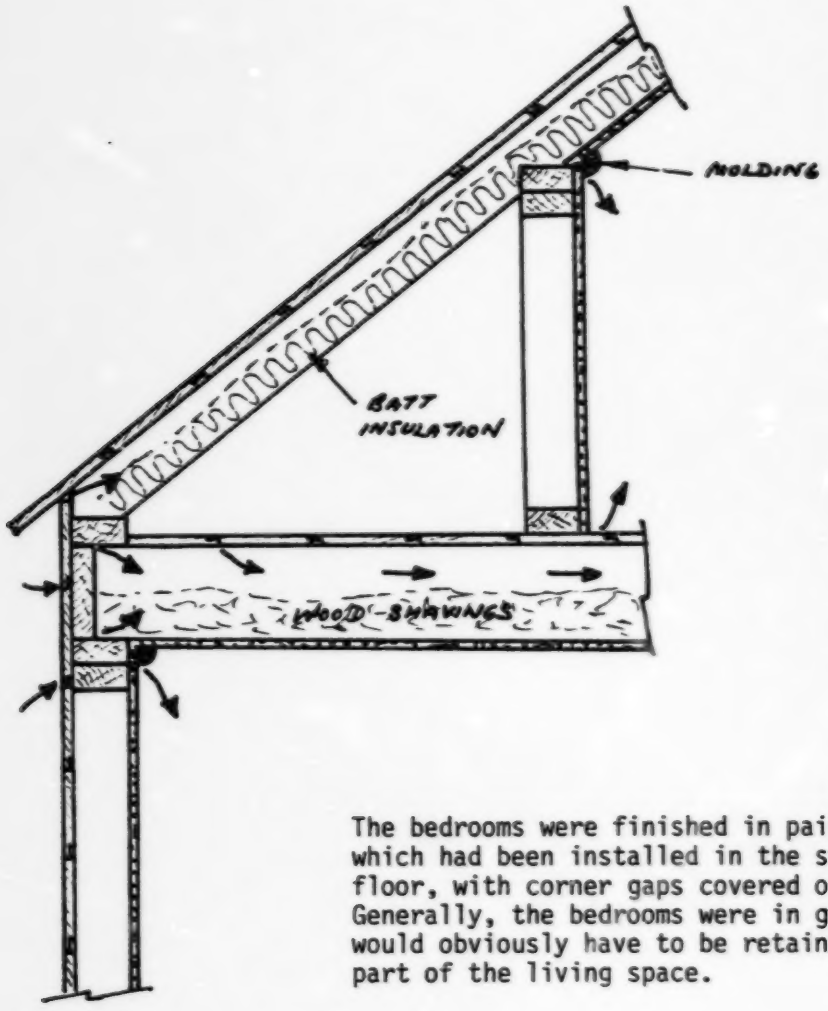
The house had a high-pitch gable roof, with a slope of about 45°. The attic consisted of a rafter construction with a half-storey development of two bedrooms. The shingles were old and needed replacing.

The attic was insulated with Kraft-backed mineral wool batt, of the same type as used in the exterior walls. This insulation had been installed between the roof rafters and between the studs on the gable walls. The whole attic area was therefore part of the heated house envelope. The batt insulation had been installed between the rafters prior to the bedroom construction; batts were found between the rafters over the sloping sections of the bedroom ceiling. An attic hatch gave access to a small triangular space above the bedrooms. On inspection, it was found that the bedroom ceiling in this area was insulated with Kraft-backed batt, with about RSI 1.0 of sawdust fill on top.

The framing was very sound, and consisted of 38 mm x 89 mm rafters on 400 mm centres.

The attic floor consisted of diagonally-laid 19 mm shiplap. A section of this was removed to allow inspection of the floor joist cavity. It was discovered that the cavity had been partly filled with wood shavings.

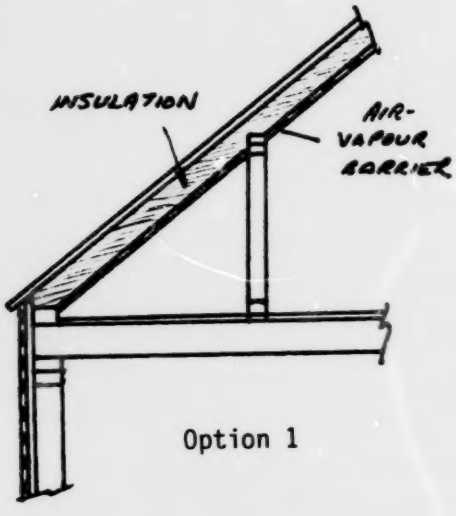
The sketch on the next page shows the main features of the attic construction. It will be clear that this part of the house was responsible for a fairly high proportion of the total heat loss - both by thermal transmission and air leakage. The structural detail around the floor joist headers is of particular interest. A large air leakage heat loss appeared to be possible at this point. The wall sheathing, consisting of diagonally-laid shiplap, has air channels at each joint, running diagonally across the outside of the floor joist header. These air channels are coupled to similar ones in the shiplap sub-floor. Therefore, there is a strong air leakage channel running from one side of the house, along the floor joist cavity and out the other side of the house.



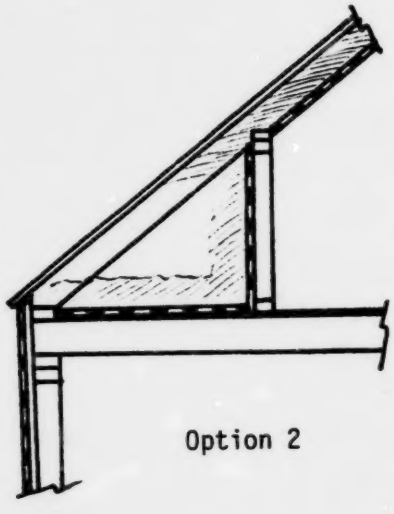
The bedrooms were finished in painted drywall, which had been installed in the same way as on the main floor, with corner gaps covered over by moulding. Generally, the bedrooms were in good condition, and would obviously have to be retained as an essential part of the living space.

6.2 Retrofit Alternatives

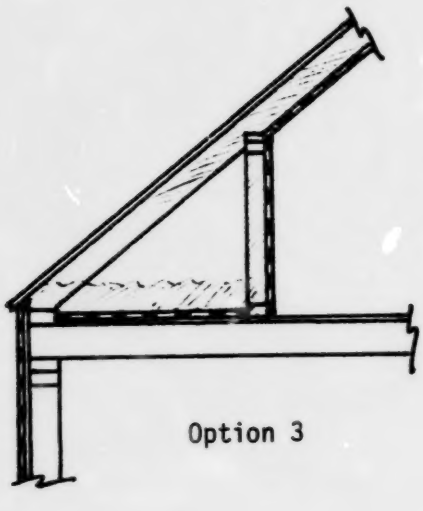
An attic in this condition can clearly benefit from both sealing and re-insulation work. The main problem is to determine the best places to install the air-vapour barrier and the insulation. In short, the retrofit alternatives reduce to a choice of house envelopes. The following series of sketches, on the next page, show some of the possible routings of the air-vapour barrier.



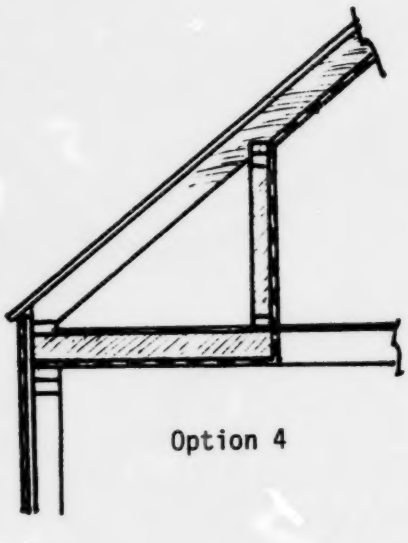
Option 1



Option 2



Option 3



Option 4

Option 1 has the advantage of retaining the triangular areas as useful storage space. However, since the installation is installed between rafters, which are only 89 mm deep, the insulation is effectively limited to RSI 2.1 - assuming that batt is used. Also, since this area will be used as living space, it will be necessary to cover the air-vapour barrier with drywall or panel. This option is relatively expensive and will result in only a small increase in thermal efficiency.

Option 2 allows a higher level of insulation in the triangular space, but creates problems in supporting the vertical insulation against the pony wall. This can be overcome by filling the entire space with insulation. The extra cost of this is not large. The air-vapour barrier is a little weak in this design since it has no support on the warm side. This can be overcome by installing batt insulation between the dwarf wall studs.

Option 3 is effectively the same as option 2, but is marginally cheaper since it uses the existing drywall as an air vapour barrier.

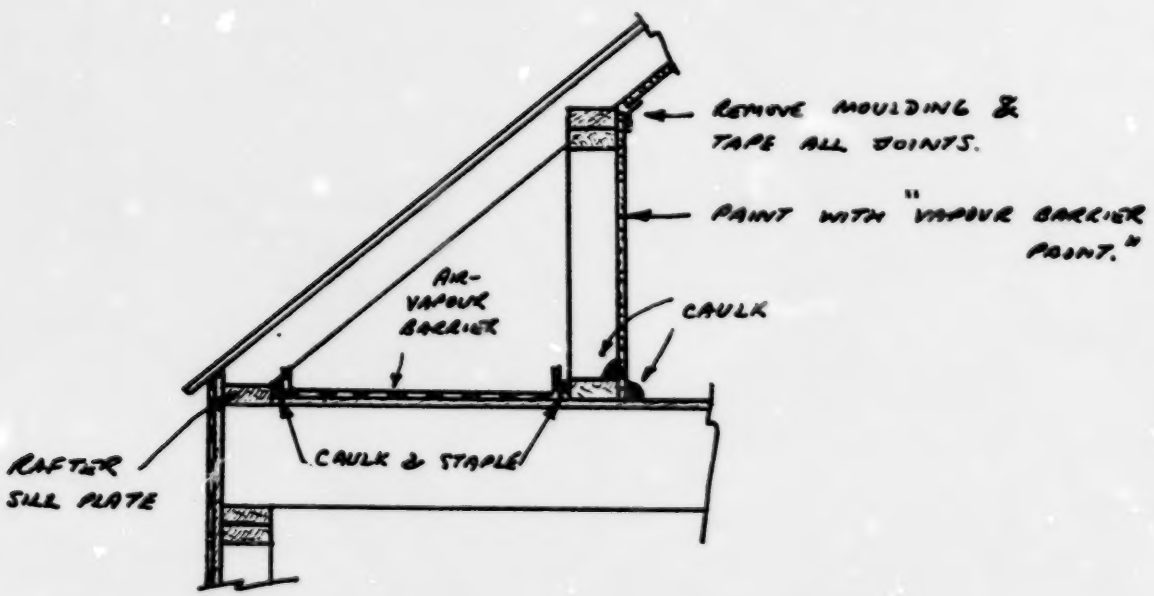
All these three options suffer from a major defect: they do not entirely eliminate the possibility of air leakage along the floor joist cavities. This leakage is reduced to a certain extent by the new air vapour barrier on the outside of the walls, but it cannot be completely eliminated because of the gaps between the diagonally-laid wall sheathing. Option 4 is the best one from the point of view of energy saving, since it achieves satisfactory insulation levels and allows a higher level of air leakage sealing. However, this can be achieved only by cutting away the sub-floor and conducting some detailed construction work between each pair of joists. A quick solution is to fill this space with foamed-in-place insulation, which would also serve as an air-vapour barrier. But it would be very costly to do this with the right degree of quality control.

6.3 Factors affecting the choice

Option 3 was considered to be the best one, for the following reasons:

- It allowed the installation of relatively high levels of insulation at relatively low cost, without intricate installation procedures.
- The air-vapour barrier work would be simple and inexpensive.
- It was proposed to use the bedroom walls and ceiling as part of the air-vapour barrier. Since these could have benefitted from a coat of paint, this created an opportunity to demonstrate the use of a new type of vapour barrier paint.
- The loss of the triangular storage spaces caused some concern, but it was felt that this loss would be more than balanced by the space made available in the basement, as a consequence of proposed changes in the heating system.

Accordingly, it was decided to adopt Option 3. The problem then lay in translating this into a detailed design. To be effective, the air-vapour barrier and the sealing work had to be directed at the following

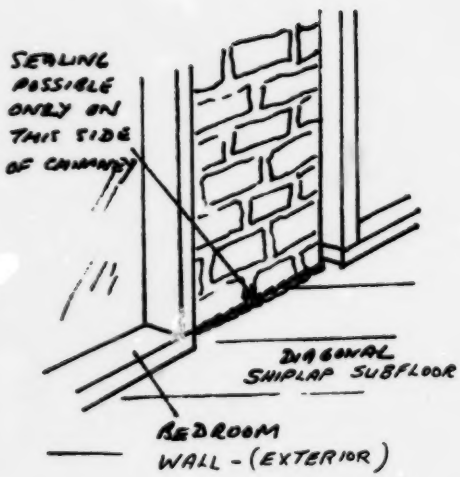


points, referring to the sketch on the preceding page:

- It is not practicable to attempt a perfect joint between the air-vapour barrier on the exterior wall and the air-vapour barrier on the attic floor; there are too many obstructions. The gap between the two air-vapour barriers must therefore be bridged by the rafter sill plate. This is far from ideal, but the seal can be improved slightly by caulking the air-vapour barrier to the side of the sill plate.

- A similar problem exists at the sill plate of the dwarf wall. Here, the sill plate bridges the gap between the floor air-vapour barrier and the painted bedroom wall drywall. The seal can be improved by caulking at the points shown.

- The bedroom drywall had major air leakage points in the corners, where the open joints were concealed by corner moulding. This moulding had lifted off in several places. It was decided to remove the moulding, tape and sand the joints to reduce moisture movement by air leakage. The entire wall and ceiling were then painted with a "vapour barrier paint" to reduce moisture movement by diffusion.



Even with this attention to detail, it was anticipated that the final seal would only be moderately good. The gap between the two air-vapour barriers, at the rafter sill plate, contains the tops of the diagonally-laid shiplap sheathing, which has a large air leakage gap at every joint. These constitute air leakage holes through the air-vapour barrier joint. A similar problem occurs under the dwarf wall sill plate, which rests on diagonal shiplap with air gaps that destroy the effectiveness of the seal at this point. A third area of air leakage occurred where the chimney passed through the attic floor. The chimney was surrounded on three sides by the framing of the bedroom walls, and it was virtually impossible to conduct any sealing work anywhere but on the exposed side of the chimney.

From airtightness tests before and after the retrofit work, it was discovered that the retrofit work had improved the airtightness of the house by a factor of four (or approximately so). This was encouraging, but the house still remained the second leakiest of the six Conservahomes.

As one final sealing measure, it was decided to block-in the existing attic hatch and provide a new one on the north gable wall - opening into the small triangular space above the bedroom ceiling. This would simplify the installation of insulation in this area.

In insulating the attic, the problem could be divided into three parts:

- The triangular spaces on each side of the bedrooms.
- The triangular space above the bedrooms.
- The small gaps (89 mm) between the roof sheathing and the sloping sections of the bedroom ceiling. This area also included a similar gap at the top of the stairwell leading into the attic (see sectional view in figure 1).

The general strategy was dictated by the last part: the small gaps over the sloping ceiling sections. The existing insulation in this area consisted of Kraft-backed batt (RSI 0.88 to RSI 1.2). This occupied only 60% of the available cavity. It was therefore decided to remove the existing insulation and fill the cavities completely with new insulation. Batt insulation would have been out of the question in this area, since a large number of shingle nails protruded through the roof sheathing into the cavity. Therefore the area would have to be insulated with a loose-fill material installed from the space above the bedrooms.

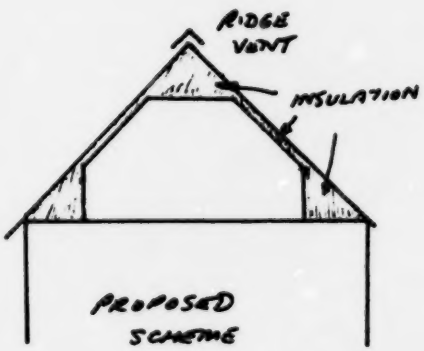
This suggested that the space above the bedrooms should also be insulated with loose-fill material, so that any settlement in the sloping sections would automatically be replenished by material from the space above the bedrooms.

Loose-fill material or batt would have been suitable for the floors in the storage spaces on each side of the bedrooms, but batt material was the obvious choice for the dwarf wall because it could be installed easily.

Consequently, it appeared that the attic would have to be insulated with two different types of material: loose-fill and batt. It was thought that this might involve some cost penalties, since some insulation companies deal with only one type of material. On further consideration it was realised that loose-fill material could be used throughout, provided that the spaces on each side of the bedroom were filled completely. This alternative was investigated. It was found that it would require little extra insulation and would allow all the attic to be insulated by the same process.

This led to the choice of loose-fill material. At that time, loose-fill mineral wool was hard to get, and the choice centred on cellulose fibre and glass fibre. If cellulose fibre had been used, it would have been necessary to provide effective ventilation through each of the insulated areas - since this material tends to suffer from the effects of moisture build-up. Glass fibre, on the other hand, is relatively immune to these effects, and would not require much in the way of ventilation.

It was therefore decided to insulate the attic with loose-fill glass fibre, while taking special care to ensure that all the available spaces were totally filled with this material.



Bearing in mind the attempts that would be made to improve the airtightness of the house, it was felt that there would be little risk of moisture exfiltration into the attic spaces. With time, however, there would be some risk of water penetration through leaky shingles. It was decided to provide the attic with a ridge vent that would allow moisture to dissipate from the whole insulated area.

6.4 Details of the upgrading work

Preparation:

The attic hatch above the stairwell was removed, and replaced with a new hatch on the north gable wall, giving access to the space above the bedroom

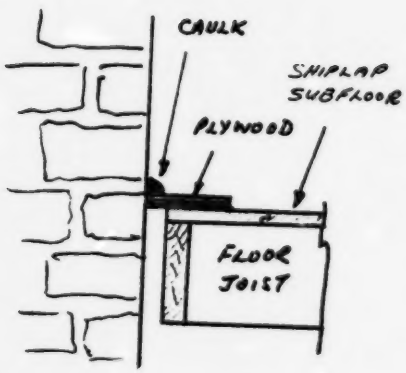
ceiling. Towards the end of the attic work, the original hatch was blocked-in, drywalled and painted.

In the attic plan in figure 1, it will be noted that there were three storage spaces alongside the bedrooms, each with an access door through the pony wall. These doors were removed and the openings were framed in preparation for blocking-in on completion of the insulation work.

The trim was removed from around attic windows. The corner moulding on the drywall joints was also removed.

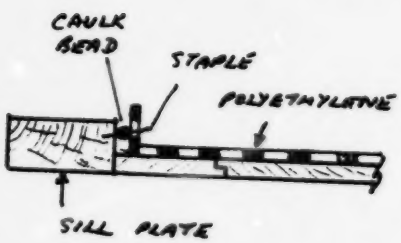
Air-vapour barrier and sealing:

The bedrooms contained three ceiling light fixtures and three wall outlets, with easy access from the back. Sections of polyethylene sheet were installed around the back of these units, and were caulked and stapled to give an airtight seal.

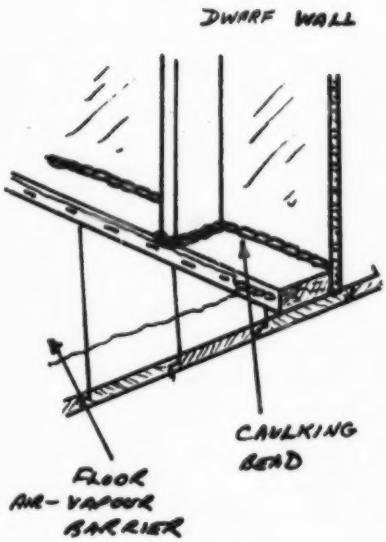


An attempt was made to seal around the chimney where it passed through the attic floor. Some parts were inaccessible. On the accessible parts the gap was too large to be bridged by caulking. A piece of plywood sheet was nailed to the floorboards to bridge the gap, then caulk was applied along the narrow gap between the plywood and the brickwork.

Urethane foam sealant, from an aerosol can, was used to seal the air gaps around the window frames.



A single piece of polyethylene sheet was installed over the full floor area in each of the three spaces alongside the bedrooms. A continuous bead of caulk was run around the sill plates in each space, and the polyethylene sheet was stapled through the caulk into the sill plate, to provide a continuous seal around the edge.



A continuous bead of caulk was run along the joint between the dwarf wall bottom plates and the back face of the bedroom drywall. Note that, even with the floor air-vapour barrier in position, this joint was still an air leakage point.

The gaps in the corners of the walls, as revealed when the corner moulding was removed, were sealed by normal drywall taping procedures and sanded in preparation for painting.

Insulation:

The existing batt insulation was removed, as far as possible, from the rafter cavities behind the sloping sections of the bedroom ceilings. The same was done for the insulation behind the sloping ceiling above the stairwell. This insulation was used as part of the new insulation fill in the storage areas. The access openings to the three storage areas were then closed off. Two of the openings were covered with drywall, which was taped and sanded in the normal way. The third opening was covered with a transparent acrylic panel to allow viewing of the insulation work during the demonstration phase.

The storage areas were filled with blown glass fibre insulation by the removal of the roof shingles and a single strip of shiplap roof sheathing above the storage areas. Care was taken to ensure a complete fill of each storage space.

Working from the attic space above the bedroom ceilings, blown glass fibre was inserted in the rafter cavities over the sloping ceiling sections. Since these cavities contained some blockages in the form of numerous shingle nails, special care was needed to ensure a good fill.

Before insulating the space above the bedroom ceilings, the old attic hatch was covered with drywall, which was then taped and sanded. The space was then filled with blown gas fibre, using the new attic hatch for access. On completion of this work the new hatch was screwed firmly in position.

Finishing work:

All drywall in the bedrooms and upper stairwell was painted with a vapour barrier type paint.

A small strip of sheathing was removed along the full length of the roof ridge. This presented an opportunity to inspect the level of the insulation fill. The contractor was asked to add more insulation if necessary. On completion of this work a ridge vent was fitted along the full length of the ridge.

The strips of roof sheathing and roof shingles were replaced with new materials. During this work the chimney flashing was repaired.

Window trim was re-installed, nail holes were filled and the window frames and trim were painted.

7.1 Assessment

With the exception of a fixed, sealed picture window in the living room, all the windows in the wood-frame structure were of the traditional double-hung type. Some had wood-framed storm windows and some had aluminum-framed ones.

During the preliminary inspection, the weather was exceptionally cold and several of the window units displayed extensive condensation on the inner faces of the storm windows - even though the house had not been occupied for some time and the relative humidity was low. The condensation indicated that, on most window units, the seals were poor, the storm windows were more tightly sealed than the double-hung sashes.

Further evidence of leakiness was seen on the kitchen, bathroom, and east-facing bedroom windows. The glass and woodwork were in poor condition due to excessive moisture deterioration of the window sashes and main frames. An attempt had been made to stuff batt insulation in the cracks between the deteriorated sashes and frames in order to reduce the large volume of air infiltration through the window unit. These units would require extensive repair or complete replacement.

The basement windows consisted of two separate wood sash units: the inner sash being hinged for use as a ventilator in summer; the outer sash being attached with hooks from the inside for use as a storm window in winter. The condition of the woodwork was poor to moderately good, and could be brought up to a satisfactory level with some repair work and a good coat of paint.

In terms of thermal transmission heat loss, the picture window in the living room was the worst of all the windows, by virtue of its large area and its double glazing. This window faced west and received relatively little solar gain.

The doors were in poor condition. The woodwork had deteriorated and the amount of glazing in them was excessive for non-south-facing units. Weatherstripping was virtually non-existent. The storm doors were made of aluminum and were generally in good condition, though requiring some metal repair work.

7.2 Retrofit Alternatives

Double-hung windows:

A good double-hung unit, with a combination storm window, usually has a slightly better thermal resistance than a conventional double-glazed unit with a 12 mm air gap. However, it is often prone to considerable air leakage around the moveable sash, and this may sometimes account for most of the heat loss through the window. When this leakage become apparent, most homeowners try to remedy the situation by sealing around the storm units. This is a bad practice. Humid house air will exfiltrate through the gaps in the double-hung unit and will accumulate as condensation or frost on the storm window. Eventually, this will run down the window and cause progressive moisture damage to the sill. The best course is to keep the storm windows moderately leaky and try to seal the double-hung unit.

When a double-hung unit is in poor condition, it is often preferable to replace it. In this case the kitchen, bathroom and one window in the master bedroom were considered beyond repair due to excessive moisture damage to the main frames and window sashes. Replacement was the only reasonable course of action. All other double-hung windows were good enough to justify rehabilitation.

Picture window:

Being a fixed, sealed, double-glazed unit, this window had a fairly high transmission heat loss and a minimal air leakage heat loss. If it had been a south-facing unit, it would probably have received more solar heat gain than the heat lost by transmission. In this case, it would have been appropriate to do nothing but repair and paint the window frame. However, the window faced west, and was a net heat loser. Therefore, there were two obvious alternatives:

- retain the window in its present form;

- thermally upgrade the window in some way.

Basement windows:

Two options were available: either rehabilitate the windows or replace them with new units. In this case there was not much to choose between either course, from the point of view of costs. If the windows were to be rehabilitated, they would also have to be fitted with frame extensions to match the new wall line. On the other hand, if the windows were to be replaced, they would have to be custom-made to fit the non-standard wall thickness.

Doors:

The doors needed to be replaced with new units. The choices therefore reduced to the selection of door type: solid wood-core door or metal thermal type (metal skin with foam insulation). At that time the solid-core wood units were substantially cheaper than the metal thermal units, and were a more cost-effective energy saving option.

7.3 Factors affecting the choice

It had already been decided to insulate the exterior walls as described in Section 5. This meant that all the window units would have to be modified to match the new wall thickness. The double-hung windows that were good enough to be thermally upgraded by rehabilitation and simple sealing techniques would require some sanding and painting made necessary by the frame extension work.

The gaps around the outside of the window frames were to be sealed as part of the wall retrofit, therefore it was only the sliding sashes on the double-hung units that required further sealing work. These sashes generally display air leakage all around their frames. It is relatively easy to seal at the top and bottom of the frame, using foam weatherstrip, but it is difficult to install a good sliding seal on the sides of the frames. It was therefore decided to conduct a simple sealing job, consisting of the installation of foam weatherstripping at the meeting rails and on the sill beneath the sliding sash. Also it was proposed to fit new sash locks to give a tighter pull-in at the meeting rails. Therefore rehabilitation and sealing was the obvious choice for these units.

Kitchen Windows (W5, W6)

The existing double-hung kitchen windows had extensive moisture damage to the frames and sashes. Rehabilitation and sealing of the window units could not be justified as a cost-effective option. The units would need to be replaced with new window units, the selection of which is based on the following considerations.

The kitchen living area is normally a source of considerable moisture generation due to such household tasks as cooking and dishwashing. Kitchen windows are therefore exposed to conditions of high relative humidity, often over prolonged periods. Windows which are constructed with poor air seals or have cold exposed interior surfaces, promote condensation problems and generally deteriorate very quickly unless constantly rehabilitated.

Summer ventilation by either natural or mechanical means is another desirable feature in a kitchen area, to control internal heat gains generated by household tasks. Replacement windows should be openable to allow for ventilation by natural means.

It is proposed to replace window (W6) with a triple-glazed fixed sealed wood framed unit and window (W5) with a hermetically sealed double-glazed wood casement type with clip-on storm window. The selection of these units would provide windows which will minimize heat loss by air leakage and thermal transmission, yet allow adequate ventilation of the kitchen area by natural means.

Bathroom Window (W4)

The double-hung bathroom window also extensively damaged, and beyond repair, because of constant exposure to high humidity conditions common to most bathrooms. The selection of a replacement window required similar considerations as the kitchen units. A triple-glazed fixed sealed wood frame unit is a most obvious choice, as an openable window is not a requirement with the newly installed mechanical bathroom ventilation system (see Section 7).

Bedroom Window (W3)

Moisture damage to the bedroom window (W3) was similar to both the kitchen and bathroom window units. It was proposed to replace the damaged unit with a triple-glazed fixed sealed wood frame unit to reduce heat loss by air leakage and thermal transmission. Window (W2) remained as an openable window to provide ventilation within the master bedroom.

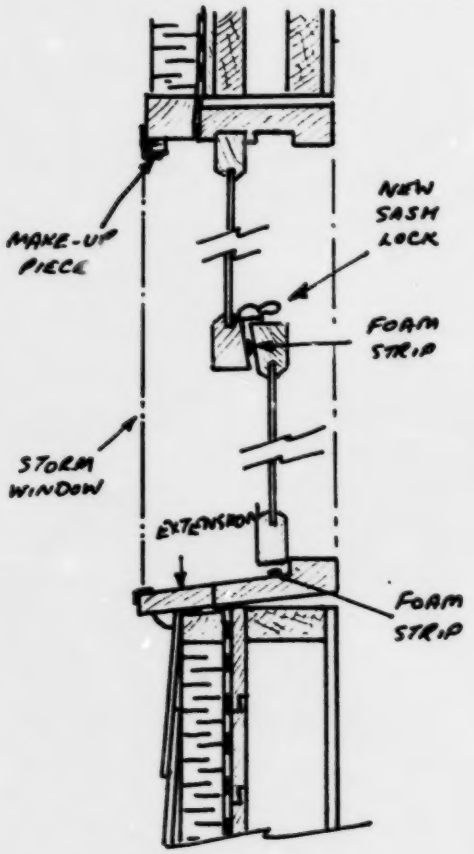
On investigation, it was found that it would be marginally cheaper to rehabilitate the basement windows than to replace them. It was therefore decided to pursue this course. The window frames on these units would also have to be extended to match the new wall line, and it was proposed to rehabilitate the units at the same time. It was felt that the basement would have adequate air circulation with the proposed new heating system, and it was therefore decided not to retain the windows as ventilation units. This meant that the windows could be re-assembled as fixed, sealed units, with a much reduced infiltration heat loss.

For the picture window, it would have been more cost effective to retain it in its existing form. However, it was decided to thermally upgrade the unit by installing a clip-on storm window. This option was chosen primarily as a demonstrational feature.

Solid-core wood doors were selected as replacement units, primarily because of their lower cost, but partly because a more thermally efficient unit would not have been consistent with the performance of the rest of the house. It was originally proposed to repair and replace the existing storm doors, but it was finally decided to install new ones, to improve the appearance of the house.

7.4 Details of the upgrading work

All storm windows were removed prior to the wall retrofit work. The existing double-hung window units (W3, W4, W5, W6) including both door units were also removed at the same time and new units were installed before the exterior air-vapour and door units were supplied with frame extensions to match the new wall thickness.

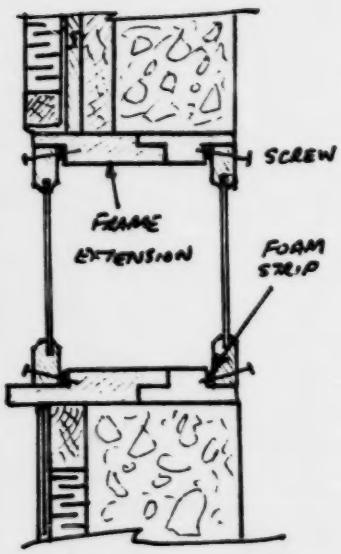


All remaining window frames were extended to match the new wall thickness, as described in Section 5. On completion of this work all wood frames were repaired, sanded and painted.

The sliding sashes in the double-hung units were removed, repaired, sanded and painted. Foam weatherstrip was installed on the meeting rails and on the sills, to give good seals at the top and bottom of the sliding sashes. Some attempt was made to install weatherstripping down the sides of the sashes, but this proved to be ineffective. The sashes were re-installed and fitted with new sash locks, adjusted to give a tight pull-in at the meeting rails.

The sashes on the basement windows were removed, repaired, sanded and painted. They were then fitted with foam weatherstripping and attached firmly to the frames with brass screws, so as to give an airtight seal.

Because of the window frame extensions, and the increased fall on the window sills, it was necessary to fit a make-up strip at the top of each of the double-hung window frames, so that there would be no gaps when the storm windows were re-installed. All storm windows were repaired , painted and re-installed. No special sealing work was conducted around the storm windows, the intention being to keep them slightly more leaky than the double-hung units.



A custom-made aluminum-framed storm window was installed on the exterior of the picture window.

New storm doors were installed on the door units, and the two assemblies were painted.

8.1 Assessment

The furnace was an old 'octopus' type, installed at the time of house construction. It was therefore about 34 years old, and had been converted from coal-fired to natural gas-fired. Its condition was poor, though it might have operated for at least another five years without trouble, owing to its rugged construction. The measured thermal efficiency was 66%.

Both the furnace and its associated ducting were very large, and occupied a substantial part of the basement area. The layout is shown in one of the plan drawings in figure 1. It is fairly obvious that, had the owners wished to develop the basement as useful living space, they would have been deterred from doing so by the obstruction of the furnace system.

The furnace flue was run inside a brick chimney, which displayed a number of cracks that might have been responsible for air leakage heat losses.

The water heater was in reasonably good condition and was judged to have a few years of life before it needed replacing.

8.2 Retrofit Alternatives

There were two good reasons for replacing the furnace with a new unit: first, it would create a lot more space in the basement and would indirectly increase the value of the house; secondly, it would add to the demonstrational impact of the house. There were no strong reasons for retaining the furnace, and it was fairly obvious at the outset that it would have to be replaced.

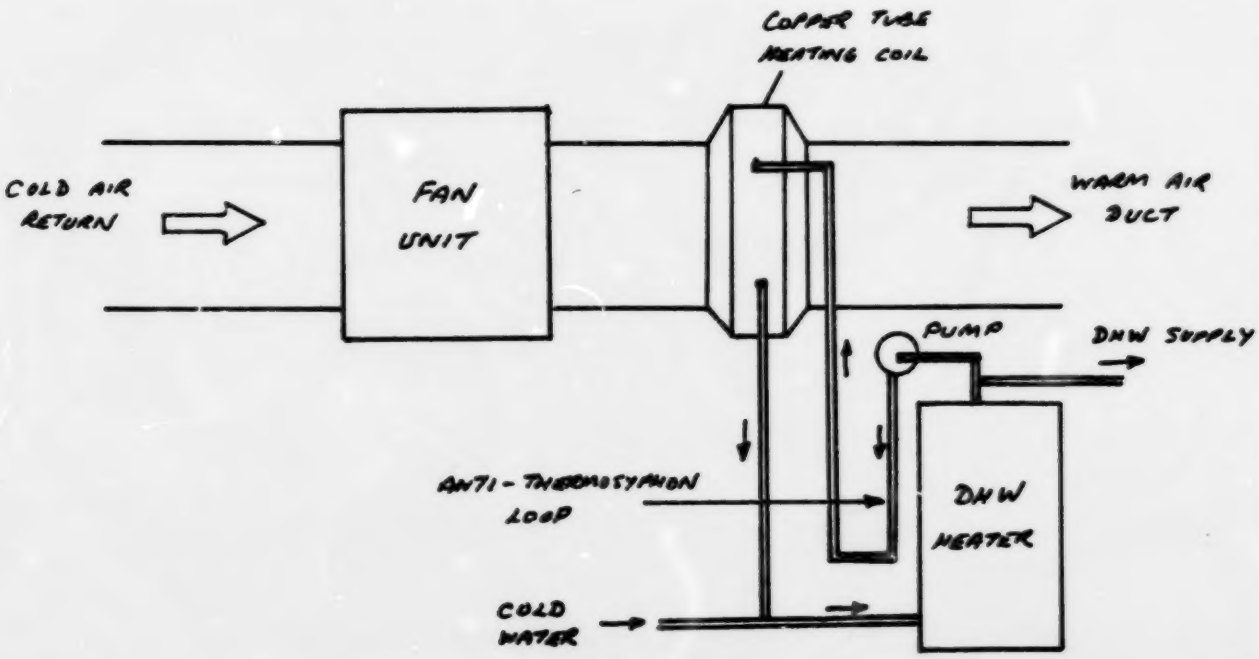
There were three replacement options:

- A standard natural gas unit
- One of the new furnace designs with automatic flue damper, electronic ignition, two-speed fan and an increased thermal efficiency.

- An innovative heating system.

The possibility of using an innovative heating system arose as a result of several factors. The heating requirements of the retrofitted house were estimated to be very small, due to the improved thermal efficiency, the small size of the house and the slightly milder prairie climate around Swift Current. Based on estimates of the final house performance, the required furnace capacity was calculated to be 6.6 kW (about 22,000 Btu/hr). At that time, the smallest available natural gas furnace had a capacity of about 16.5 kW. This would have been oversized by a factor of 2.5 and would have suffered some decrease in efficiency as a consequence.

The solution was found in one of the houses in the Saskatoon Energy Showcase project*, which was proceeding concurrently with the Conservahome Project. The house in question was very energy efficient, and the designers had encountered the same problem of oversizing with the smallest available furnaces. They had devised a space heating system that used hot water from the domestic hot water heater:



* The Energy Showcase Project was a block of 14 super energy-efficient houses built in Saskatoon in 1980.

The fan is a two-speed unit. The pump is a sealed unit that will not contaminate the domestic hot water supply. The domestic hot water heater is sized slightly higher than a normal domestic unit, and has a capacity of 15 kWh (50,000 Btu/h).

When the house requires heat, the thermostat activates both the pump and the fan; the latter being switched from low-speed to high-speed operation. Hot water is pumped through the heating coil, and ducted air is blown across the coil. This warmed air is then distributed around the house through a normal warm-air ducting system. When the house has reached the required temperature, the thermostat de-activates the pump and the fan. The fan continues to operate at low speed, to give good air circulation around the house. This continuous air circulation is generally advisable in an energy efficient house, which experiences little air movement from infiltration or thermal convection.

In sizing the domestic hot water heater for its dual heating role, it should be noted that the highest space heating requirements usually occur between midnight and 0600 hours, when there is little demand for domestic hot water.

8.3 Factors affecting the choice

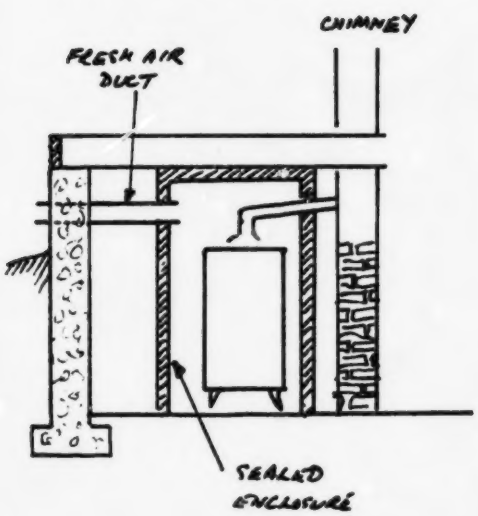
Because of its obvious demonstrational impact, it was decided to install the innovative coil heating system. Such a system helps to make the point that a house can be made so energy efficient that it requires very little heating.

With the removal of the existing furnace, it would be necessary to re-build the entire main ducting system in the basement. The coil heating system could be combined very easily with this re-build.

At an advanced stage of the retrofit work it was discovered that the existing furnace flue would be incorrectly sized for the new heating system. A smaller diameter flue was needed to set up the right draft conditions for the smaller heating

capacity of the domestic hot water heater. Accordingly, arrangements were made to install a 100 mm diameter stainless steel flue inside the existing flue liner.

It was estimated that the retrofitted house would be more airtight than was eventually achieved. On the basis of the estimated airtightness, it was felt advisable to install a controlled combustion air supply to the domestic hot water heater. Without this, there was a risk that ventilation systems would cause the flue to backdraft, thereby adding harmful combustion gases to the house air. Since 1980 this problem has been considered many times in tightly sealed houses, yet there is still no general agreement on the best way to overcome the problem. Some people recommend a simple fresh air duct through the exterior wall, close to the combustion unit. Others recommend a more controlled design, in which the combustion unit is surrounded by a reasonably airtight enclosure, which has its own fresh air supply from outdoors. Each approach has its advantages and disadvantages, and far more research and evaluation is needed to resolve the issues.



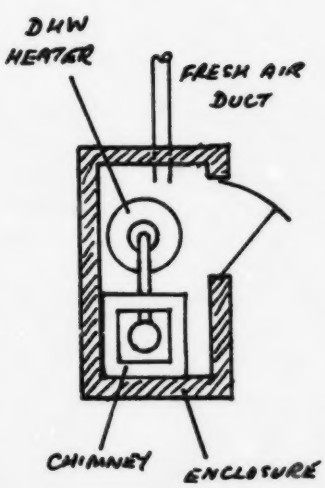
It was decided to adopt the more controlled approach, by installing the domestic hot water heater inside a reasonably airtight closet and providing a fresh air duct into the closet. This approach has two advantages: first, it provides a good safeguard against fire hazards and the accidental release of combustion gases into the house air; secondly, it isolates the draft effect of the flue from the rest of the house. This tends to reduce the rate of natural infiltration through the house envelope, and leads to a further improvement in the overall thermal efficiency of the house. The same process also creates a greater risk of moisture exfiltration into the house envelope, where it may cause structural damage. But in this instance it was estimated that the retrofitted structure would be adequately protected against this effect.

8.4 Details of the upgrading work

The existing furnace unit and domestic hot water heater were dismantled and removed. To achieve this it was necessary to cut the furnace into small pieces. The large ducts in the basement were also dismantled and removed.

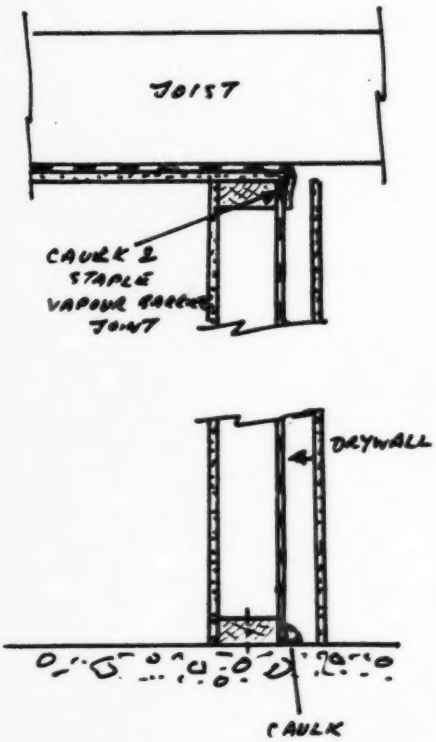
A new ducting system was installed to current ductwork standards. This was connected to the existing lateral ducts leading to the upper storeys. On inspection, some of the existing lateral ducts were found to serve no useful purpose. These were closed off at this time, and the holes at the wall registers were repaired with drywall. The hall floor contained a very large cold air return grille. This was removed and the floor was modified to accept a smaller register. As a result, it was necessary to replace the hall carpet. Other minor changes were made, to improve the efficiency of the existing duct system.

A fan unit and coil heater system, as detailed on page 41, were installed in the new duct system. The specifications of these units are given in Appendix I.



It was decided to construct the sealed enclosure around both the domestic hot water heater and the chimney. This would simplify the construction of the enclosure by eliminating the need to seal around the hot flue connection. The new domestic hot water heater was therefore positioned close to the chimney. A new flue (100 mm diameter stainless steel) was installed inside the existing one, working from the top of the chimney. A vent connector was installed from the domestic hot water heater to the new flue. The various cracks in the chimney mortar were sealed with caulk and mortar.

A sealed enclosure was built around the DHW heater and the chimney. The enclosure consisted of a 38 mm x 89 mm wood frame with vapour barrier on the outside and drywall on both the inside and outside. It was made large enough to give good access to the DHW heater, and was provided with a weatherstripped hollow core mahogany door.



The method of construction of the enclosure was designed to facilitate an airtight construction. First, the outline of the enclosure was marked on the floor joists, which would support the ceiling of the enclosure. A large piece of polyethylene sheet was then stapled to the floor joists, covering the proposed ceiling area and leaving plenty of spare material at the edges. Some special caulking and stapling work was needed to give a sealed fit around the chimney. Next, the ceiling area was drywalled, including enough drywall to protrude to the outside face of the enclosure wall. The stud frame was then installed under this drywall, and was attached firmly to the concrete floor. A sheet of polyethylene was applied around the exterior of the frame, and was caulked and stapled to provide a good airtight enclosure. The ceiling polyethylene was then folded down and caulked and stapled to the wall polyethylene to give an airtight fit. The frame was drywalled on the outside, and on accessible parts of the inside. Finally, the door was installed and provided with weatherstripping.

Copper pipe connections were made from the DHW unit to the coil heater and pump. The gas supply was connected to the DHW heater. A fresh air duct (130 mm diameter) was installed through the basement wall and into the enclosure. This duct was insulated and was fitted with a bug screen on the exterior opening. Caulking was applied around each of these facilities, where they passed through the vapour barrier into the enclosure. This work was simplified by having the vapour barrier on the outside of the enclosure.

Electrical connections were made to the fan unit and the water pump. A new night set-back thermostat was installed on the main floor and provided with a control circuit for activating the pump and fan.

On completion of this work it was inspected by the local gas authority. This authority had been notified previously of the proposed design, and had given approval. Prior approval was required in this instance, since the gas codes generally do not allow a domestic hot water heater to be used for space heating purposes.

An airtight house does not have enough natural air change to control the air quality. In this situation there can be a build-up of humidity, odour and various pollutants - some of them, such as radon, are harmful to the occupants. If there is a likelihood of poor air quality, it is therefore essential to provide the house with a controlled ventilation system.

There is no generally-accepted criterion for determining whether a ventilation system is needed or not. The minimum air change rate for a house has been set at 0.3 air changes per hour (ach) by some authorities, and 0.5 ach by others. Ventilation rates in this range are considered to give adequate protection against poor air quality. Unfortunately, ventilation is a source of heat loss: warm air is exhausted out of the house and is replaced by cold incoming air. Therefore, the higher the ventilation rate the higher will be the heat loss. This heat loss can be reduced by including a heat recovery device in the design of the ventilation system. An air-to-air heat exchanger is one such device. It extracts heat from the exhausted air and passes it to the incoming fresh air. In this way, as much as 70% of the wasted heat can be recovered.

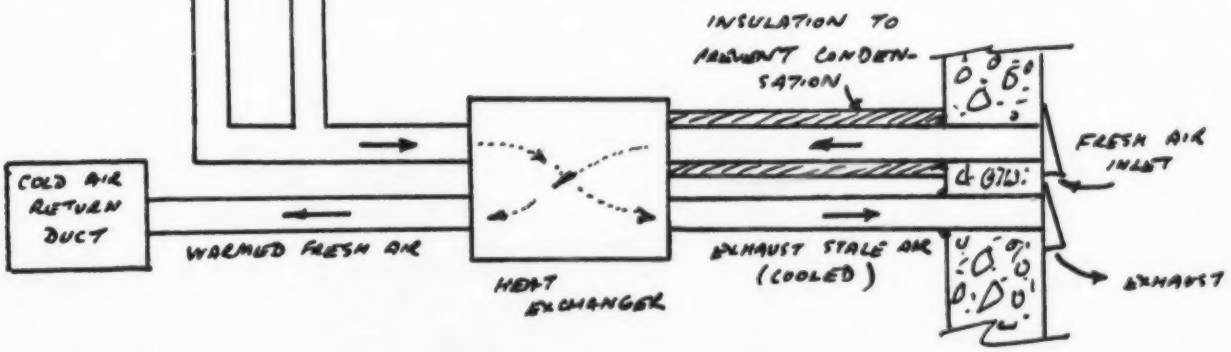
In this house, it was estimated that the retrofit work would produce a high level of airtightness. A natural air change rate of about 0.05 to 0.10 ach was anticipated. It was therefore clear that the house would need a ventilation system, with enough capacity to raise the air change rate to at least 0.3 ach. For demonstrational purposes, it was decided to include a commercial air-to-air heat exchanger in the ventilation system.

Three commercial units were generally available at that time, but for various reasons two of the manufacturers could not supply units within the required time scale. The only available heat exchanger was a small unit of Japanese manufacture. This has enough flow capacity for the job, and was therefore selected. Note that the natural air change rate was found to be 0.15 ach after comp-

letion of the retrofit work. This was higher than expected, and the house may therefore have slightly more air change than is strictly necessary.

An inlet and outlet duct were installed through the basement wall on the east side of the house. These ducts were caulked around the outside to make an airtight fit, and were provided with insect screens. Two stale air exhaust ducts were installed, to draw air from the kitchen and the bathroom. These ducts were installed inside the partition wall from below - in the basement. Some difficulties were encountered in doing this. Before selecting the location of new ducts in walls, it is first advisable to identify any obstacles such as electrical cables or plumbing. These tend to be more prevalent around kitchens and bathrooms.

The heat exchanger was connected to the new ducts as shown in the sketch below. Note that the warmed incoming fresh air was ducted into the cold air return of the house heating system. This is a good way of distributing fresh air around the house, but it has some drawbacks. The fresh air from the heat exchanger is relatively cool; its temperature may often be lower than 10°C. This air is mixed with the warmer air in the cold air return duct and is continuously circulated around the house. Therefore, unless the heating system is in operation, this cold fresh air may produce a cool draft near the warm air registers. Some people have complained of thermal discomfort in such circumstances. Further development is needed to evolve a more satisfactory way of handling the incoming fresh air.



SCHEMATIC LAYOUT

The kitchen and bathroom were considered to be in an unacceptable condition for a demonstration house. They were given a general 'face-lift', consisting of new counter tops, new medicine cabinet, repair of baseboards and painting of walls and ceiling.

It was proposed to use the basement as the main display area during the demonstration phase. To improve its appearance it was fitted with three new fluorescent light units and the walls were painted white.

For details of costs, projected energy savings and conclusions about this project, the reader is referred to the Overview Report which is the first in this series of reports.

For further details of the work, the materials and the techniques, the reader is referred to the following Appendix, which consists of the detailed specifications as given in the contract documents.